Predicting Upwelling Radiance on the West Florida Shelf

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LONG-TERM GOALS

The prediction of inherent optical properties (IOPs) and water-leaving radiance (L_w) in coastal waters over a 5 to 10 day time horizon will require a numerical simulation that accurately forecasts the physical, ecological, and optical environment. Critical to the ecological and optical forecast is the ability to directly compare the water-leaving radiance field to those being collected by aircraft and satellite platforms. Our goal is to develop the ecological and optical models and computer codes to initialize, validate, and predict the IOPs and L_w over an operational time horizon.

OBJECTIVES

1) Couple EcoSim 2.0 to a robust radiative transfer model to yield water-leaving radiance for a given IOP distribution

2) Initialize and validate spectral water-leaving radiance with remote sensing data.

3) Couple EcoSim 2.0 to the WFS version of the Regional Ocean Modeling System (ROMS)

APPROACH

The pace of development of prognostic ecological/optical data and modeling systems has greatly accelerated in recent years such that we can now reasonably discuss the likelihood of predicting red tides, and concomitant impacts on water clarity on the West Florida Shelf (WFS). Accurate prediction of water clarity and color suggests a fundamental knowledge of marine ecological systems, and the validation of such data and modeling systems would provide characterization of the littoral environment over operational time horizons. Water clarity and color are directly dependent on the IOPs of the water column and the modeling component of these prognostic systems requires a fundamental set of equations that describe the interactions between the production and destruction of the IOPs. As the IOPs of absorption, scattering, and the scattering phase function can be described by a summation of the individual components, the cycle of color can be described by equations representing the individual active color constituents, i.e., phytoplankton, organic detritus, Colored Dissolved Organic Matter (CDOM), sediments, bathymetry, and bottom classification. The description of the cycling of each component allows for feedback effects between the in-water light field and the production and destruction of color.

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14. ABSTRACT
The prediction of inherent optical properties (IOPs) and water-leaving radiance (Lw) in coastal waters over a 5 to 10 day time horizon will require a numerical simulation that accurately forecasts the physical, ecological, and optical environment. Critical to the ecological and optical forecast is the ability to directly compare the water-leaving radiance field to those being collected by aircraft and satellite platforms. Our goal is to develop the ecological and optical models and computer codes to initialize, validate, and predict the IOPs and Lw over an operational time horizon.

15. SUBJECT TERMS

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The marine optical environment may change at the same time scale of weather change, so any operational prognostic optical system would need to be embedded into a larger system of data collection and numerical modeling. Such a system would use moorings, ships, Autonomous Underwater Vehicles (AUVs), satellites, and physical/ecological/optical numerical models to provide integrated data streams to a wide community of users. The systems would need to be able to assimilate data as it became available, and provide forecasts over a wide range of time and space scales. The West Florida Shelf (WFS) is an ideal location to help develop these nowcast/forecast systems, in part due to a large number of other research programs focused on the WFS, including other ONR funded technology programs, NOAA/EPA ECOlogy of Harmful Algal Blooms (ECOHAB) program, and the State of Florida Coastal Ocean Monitoring and Prediction System (COMPS) program. The ECOHAB and COMPS programs are focused on time scales ranging from months to years and spatial scales ranging from kilometers to 1000s of kilometers. Therefore, this site provides a natural location to develop broad scale time and space models of the inherent optical properties.

The WFS is unique in other ways that make it ideal for the development of forecasting systems. In particular, the variance in color and clarity of the near-shore waters is extreme, ranging from oligotrophic Case 1-type waters to highly attenuating Case 2 waters [*Bissett et al.*, 1997; *Carder and Steward*, 1985; *Carder et al.*, 1989]. The low-nutrient and low-colored waters of the WFS are derived from the oligotrophic waters of the central Gulf of Mexico and the waters of the Caribbean Sea via the Loop Current. These waters have typical open ocean color signals. In the deeper waters off the shelf, the variations in surface color are driven by seasonal nutrients and CDOM introductions via deep mixing, as well as eddy fluxes, much like the classic understanding of Case 1 ocean color. As one moves across the shelf break onto the outer shelf, complications to the classic blue ocean signal arise from both Loop Current intrusions that bring higher nutrient waters (and CDOM) into the euphotic zone and river CDOM fluxes from the Mississippi, Mobile, and Apalachicola Rivers. In the inner shelf, the color signal becomes even more complicated as the introduction of waters from Suwannee, Hillsborough, Peace, and Caloosahatchee Rivers mix with the above water masses, as well as with those waters created locally from high energy mixing (waves, long-shore currents, etc.) and heat flux imbalances.

The ecological/optical conditions on the WFS are as complicated as any coastal region, yielding situations where the chlorophyll a biomass may range from 0.01 to >20 μg liter^{-1} at the same location during different time periods. When oligotrophic waters dominant the shelf, bottom features are clearly evident in high-resolution hyperspectral data to a depth of 30 meters. At other times, river and estuary waters dominate, and the bottom is undistinguishable in waters <2 meters deep. In between these two conditions, the color signal is mainly a function of the ecological interactions between phytoplankton growth and loss and CDOM creation and destruction. Within the inner shelf, the color signal is further modified by the bottom classification and sediment re-suspension. Our goal on the WFS is to derive and validate a set of fundamental ecological/optical/physical equations that addresses, and eventually predicts, the complexity of the IOPs and the resultant water-leaving radiance. This site is an ideal location for the regional time and space scales being studied.

WORK COMPLETED

As mentioned in the 2003 and 2004 progress reports, the previously developed Princeton Ocean Modeling developed for the WFS was not optimized for high performance computing. In addition, it did not contain the terrestrial boundary conditions that were deemed necessary to accurately resolve

the near-shore IOP distribution [*Bissett et al.*, 2005]. Thus, we sought to build upon the Regional Ocean Modeling System (ROMS; http://marine.rutgers.edu/po/index.html), and its ONR funded follow-on, Terrain-following Ocean Modeling System (TOMS; http://www.ocean-modeling.org/).

What became clearly evident on the WFS was that the physical modeling was of paramount important to the prediction of the IOPs. The IOPs are directly related to the mass constituents in the water column, e.g. absorption and scattering are in a large part a function of the pigmented algal biomass. The mass constituents have time-dependent change characteristics that are approximated in time/space as advection, diffusion, sources, and sinks equations. Thus, the 0-order problem for the prediction of IOPs is the initialization and boundary conditions of all the mass and momentum in the model. The 1-order problem is then the advection and diffusion of the masses; and the 2-order problem is the time-dependent sources and sinks. The order of importance of these problems is dependent on the time horizon of the forecast (today versus next year). If one is attempting to develop predictive simulations over the short-term, operational time horizon, then initialization, boundary conditions, as well as advection and diffusion become critical to the production of a successful forecast.

This has led us to partner with the physical modeling group at Rutgers University (RU), who are in a large part leading the development of the ROMS/TOMS code. In addition, the RU Coastal Ocean Observation Laboratory (COOL; http://marine.rutgers.edu/cool/) is in the midst of a 5 year NSF Coastal Ocean Process grant (Lagrangian Transport and Transformation Experiment, LaTTE; http://marine.rutgers.edu/cool/latte/index.htm) to discern the impacts of the Hudson River on the biogeochemical dynamics of the Mid-Atlantic Bight. A major component of this program is a dye injection program, which seeks to serve as initialization and validation data for a 4-D physical data assimilation modeling program. This program offered the abilities to couple the ecological modeling with a high resolution physical modeling effort that was focused on the buoyancy driven impacts on coastal ocean circulation. At the same time, the biogeochemical group included past ONR funded optical scientist who could provided the initialization/validation data required for the ecological/optical simulation. These combined efforts surpassed the programmatic operations on the WFS, and for this reason, we sought and obtained permission for ONR to refocus our WFS efforts on the Hudson River area of the Mid-Atlantic Bight.

Similar to the previous year, ROMS underwent another significant revision to version 2.2. However, this revision included the ability to maintain version control amongst the various ROMS developers. This suggests that the EcoSim code from this point forward with be maintained in each new update to the physical model. Hopefully this will save a lot of recoding of EcoSim with each new version release of ROMS.

In addition to the recoding of the EcoSim module of ROMS, we also ran 3-D simulations testing this code for the LaTTE region during their field campaign during April of 2005. Figure 1 shows the physical modeling results for April 19th, including the projected dye location after injection on April 11th. Of particular note are the differences in the temperature and salinity of the Raritan Bay Estuary and the Hudson River. The impact on the optical properties from these two water boundary conditions may be seen in Figure 2. The Hudson River water is laden with higher sediment concentrations, where as the Raritan waters contains more blue absorbing, lower scattering materials. The correct establishment of the nutrient, biological, and optical boundary conditions for these waters is critical to the successful forecasting of the optical properties over these short-term time periods.

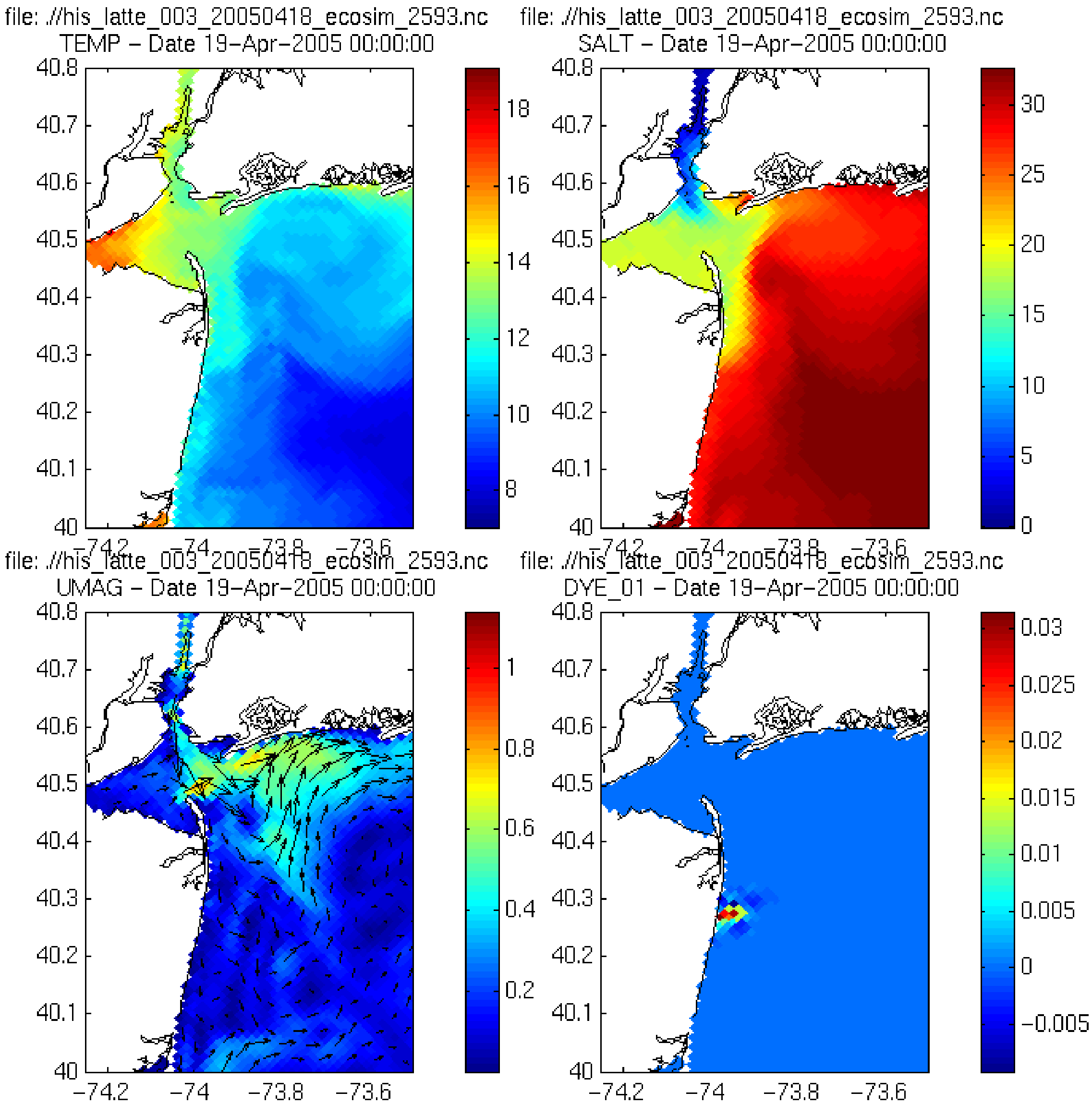

Figure 1. Three-dimensional physical results of ROMS/EcoSim 2.2 version over the LaTTE domain in the Mid-Atlantic Bight on April 19, 2005. Figures in clockwise order from top left hand corner, (1) surface temperature, (2) surface salinity, (3) dye location, and (4) current vectors overlaid on top of U component of the surface current.

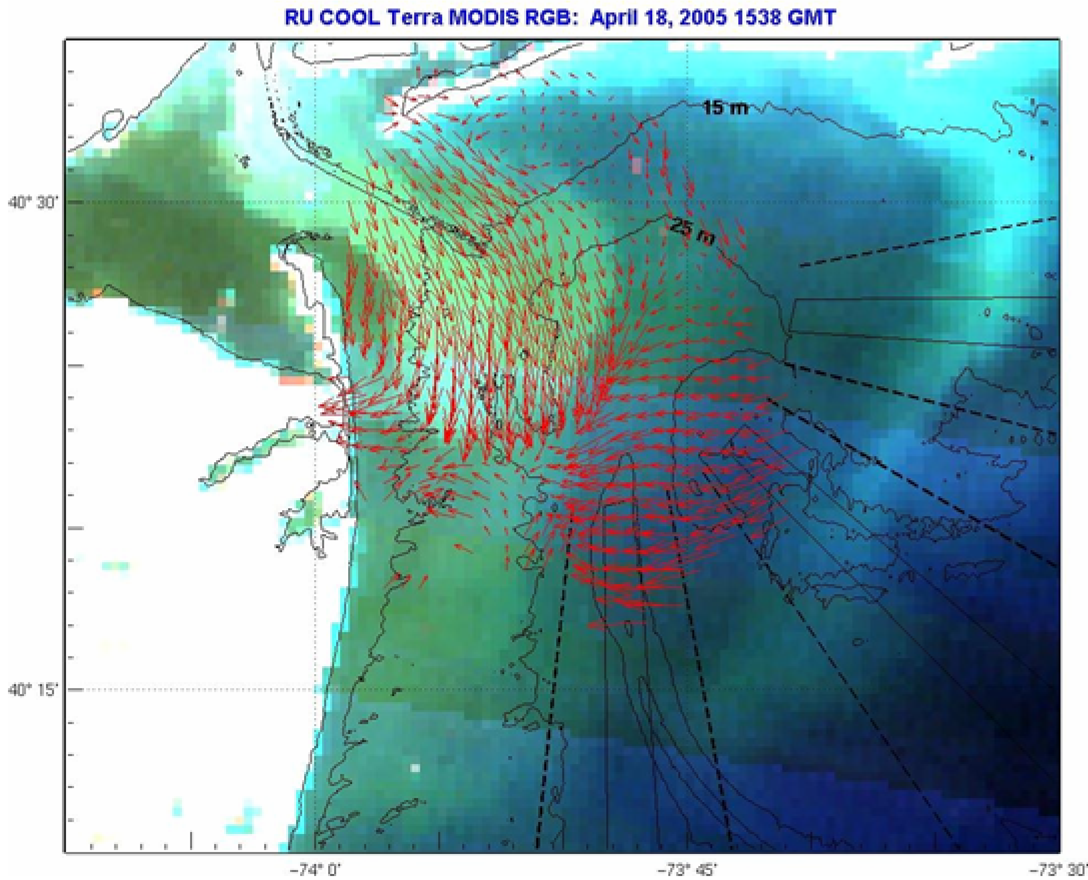

Figure 2. MODIS Terra RGB image of the LaTTE region, with the CODAR surface current field overlaid on the image. The image shows very different optical water masses originating out of the Hudson River and Raritan Bay Estuary (courtesy of Donglai Gong, Rutgers University).

IMPACT/APPLICATIONS

Forecasting IOPs over operational time horizons of 5 to 10 days will require the ability to directly compare predictions of water-leaving radiance to the data most likely to be used for initialization and validation of the predictions, i.e., aircraft and satellite hyperspectral remote sensing data. This effort will yield a simulation ready to begin direct data assimilation of the water column optical properties to predict absorption and scattering over short-term time horizons.

TRANSITIONS

The EcoSim 2.0 has been transitioned as part of the open source code of the ONR ROMS/TOMS code set.

RELATED PROJECTS

We are also collaborating with Dr. C. Mobley of Sequoia Scientific, Inc for the coupling of EcoSim with Hydrolight, and Drs. R. Arnone, NRL, and K. Carder, USF, for satellite data analysis.

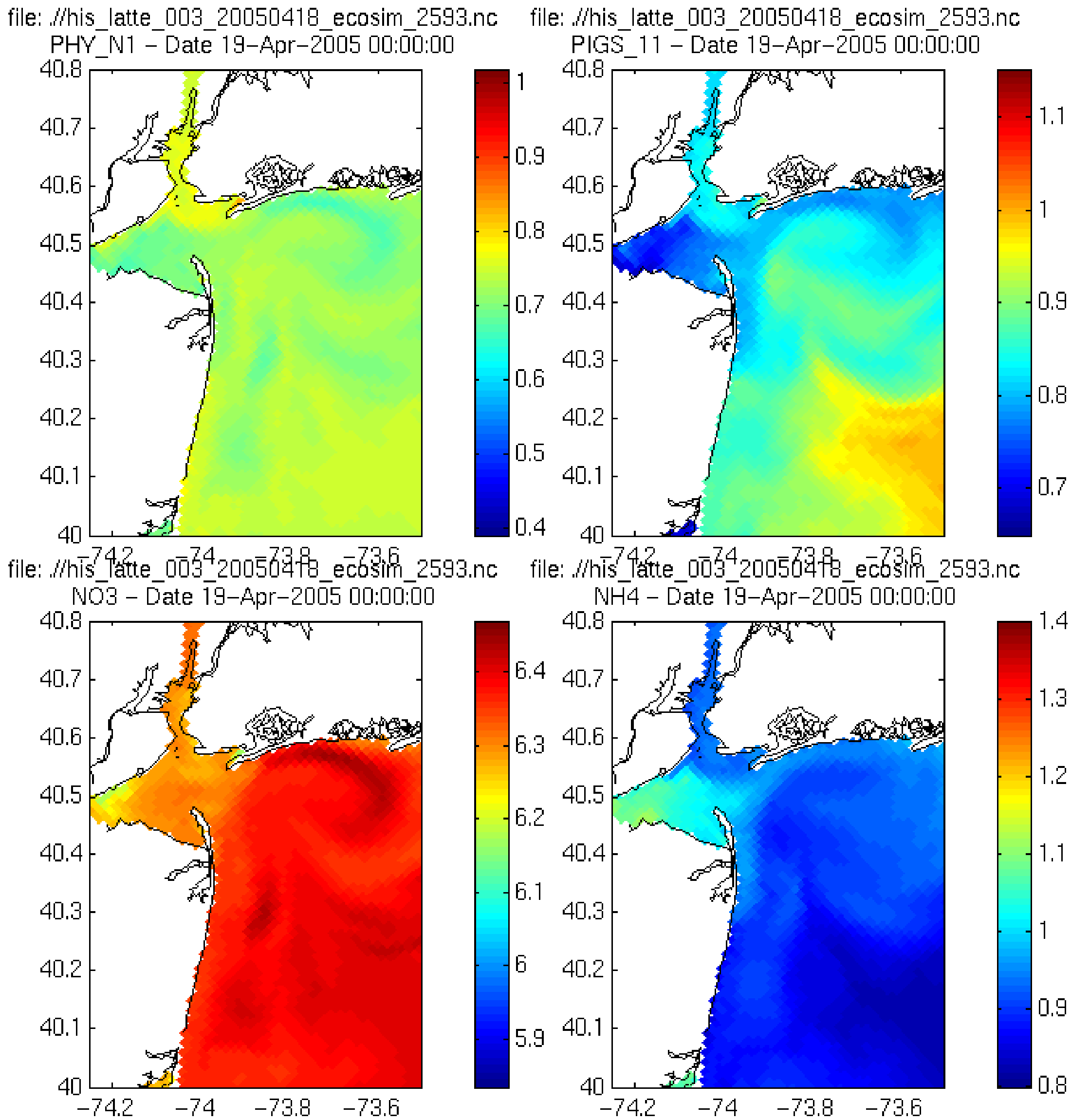

Figure 3. Three-dimensional ecological results of ROMS/EcoSim 2.2 version over the LaTTE domain in the Mid-Atlantic Bight on April 19, 2005. Figures in clockwise order from top left hand corner, (1) large diatom particulate nitrogen, (2) large diatom chlorophyll a, (3) NH4 concentrations, and (4) NO3 concentrations.

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HONORS/AWARDS/PRIZES

Semi-Finalist, 2003 Small Business of the Year, Florida Environmental Research Institute, W. Paul Bissett, Ph.D., Executive Director, Greater Tampa Chamber of Commerce.

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